# ERL and SRF Progress

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# SCA and EC Group Activities

- Establishment of SRF infrastructure
- Polarized electron guns
  - SRF polarized electron gun
  - DC polarized electron gun
- Energy Recovery Linac
  - Electron guns (including cavities, photocathodes, laser)
  - ERL accelerating cavities at 704 MHz (eRHIC, SPL, ESS)
  - The R&D ERL
- RHIC SRF cavities
  - 56 MHz store cavity
  - 28 MHz accelerating cavity
- Electron cooling
  - Low Energy RHIC electron cooling
  - Coherent electron cooling for RHIC and eRHIC

# SRF Facilities

Niobium chemistry facility:

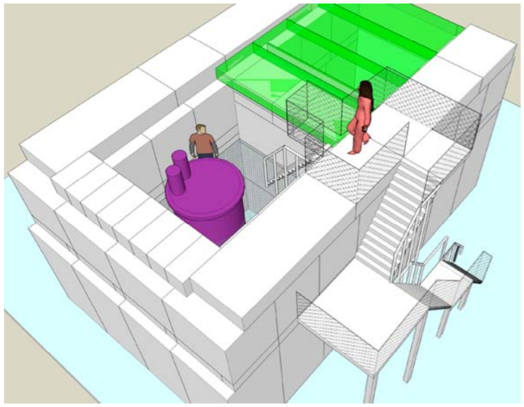
•Cutting edge technology, large cavity capability

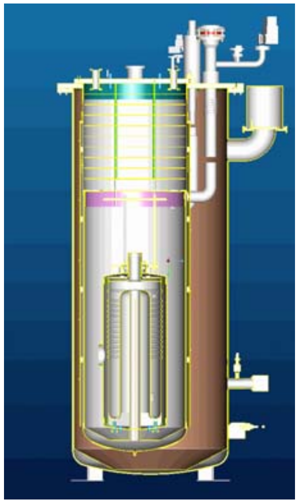
•Located at nearby AES facility with cost sharing

•Funded by BSA Patent Revenue money.

Vertical Test Facility (under construction)

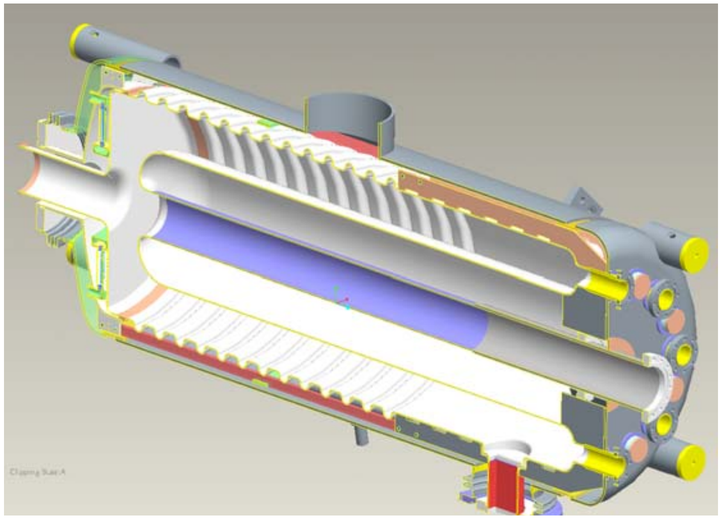
- Dewar 38” diameter 96” working depth RF systems from 56 – 1300 MHz
- LHe refrigerator with 360 W capacity, 1000 gallon storage Dewar
- Liquid ring pump for operation to 1.8K

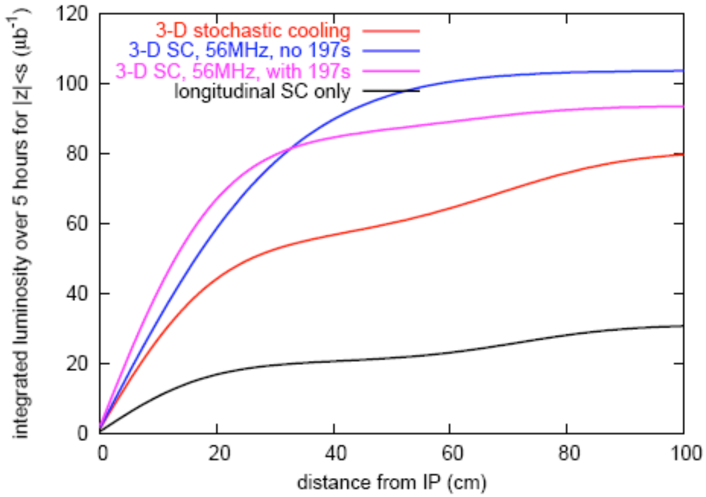




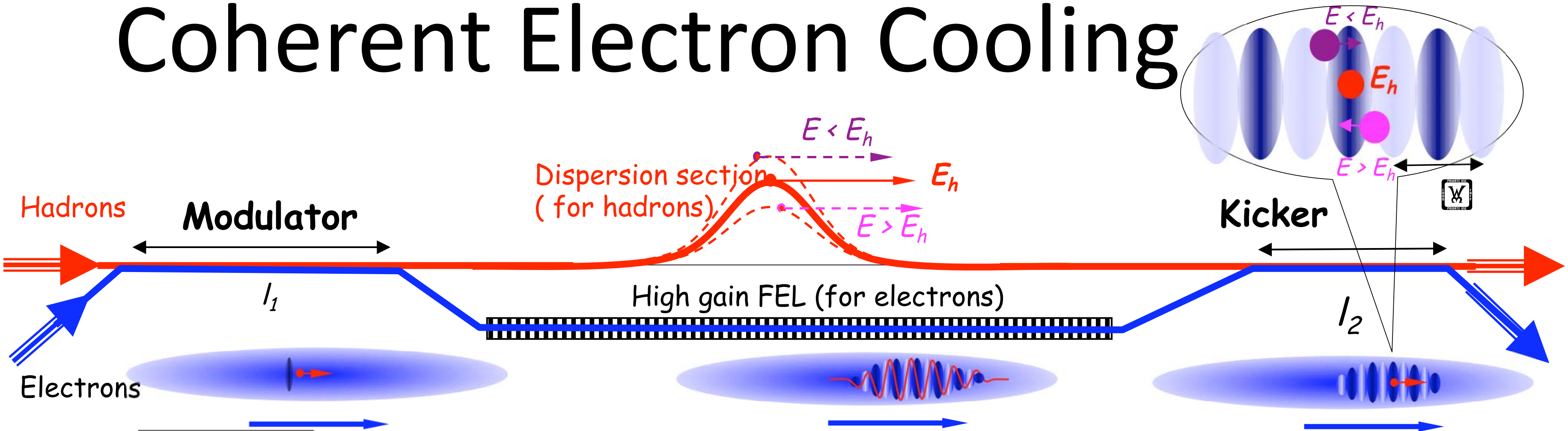
# 56 MHz cavity for RHIC

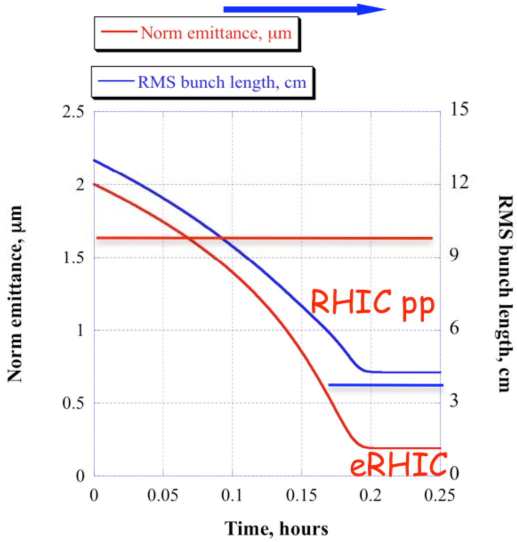
- AIP Project
  - Single cavity for both rings
  - Luminosity gain (also Low energy RHIC)
  - Adiabatic rebucketing
  - Reduction of vertex size
- Status:
  - Physics done
  - Cavity engineering done
  - Procurement to begin
  - Delays in coupler engineering

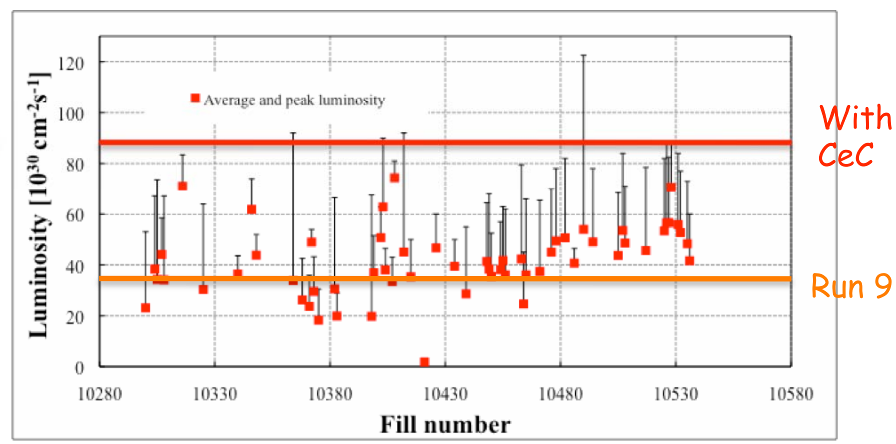




# Coherent Electron Cooling



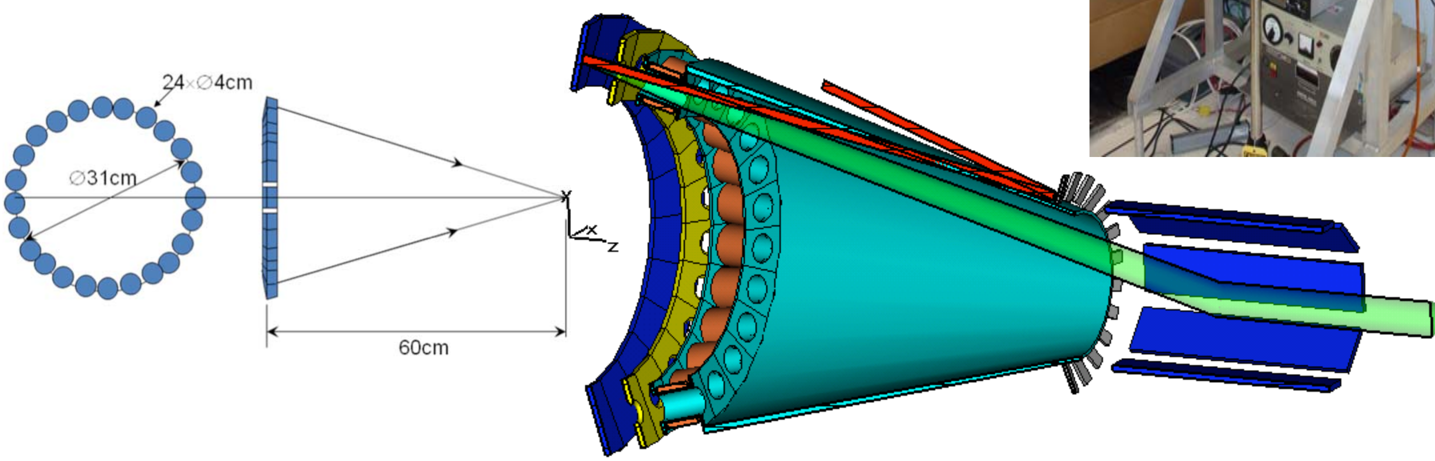




Luminosity gain for RHIC PP about a factor of 2.
Important for eRHIC: Luminosity, bunch length, reduction of electron current.
Enabled by high-brightness ERL technology.

# Polarized Electron Guns

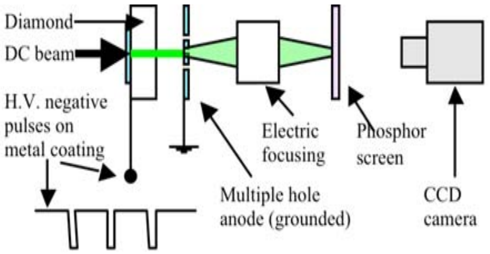
- SRF 1.3 GHz demo polarized electron gun
- GaAs preparation chamber
- Proposal for a DC "Gatling gun" for high current (50 mA)

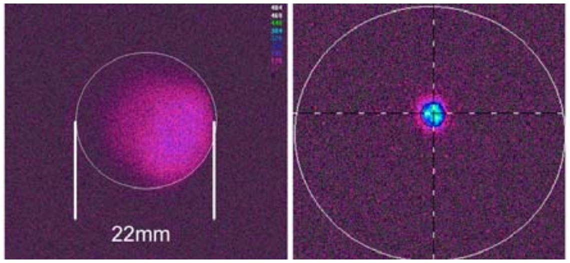


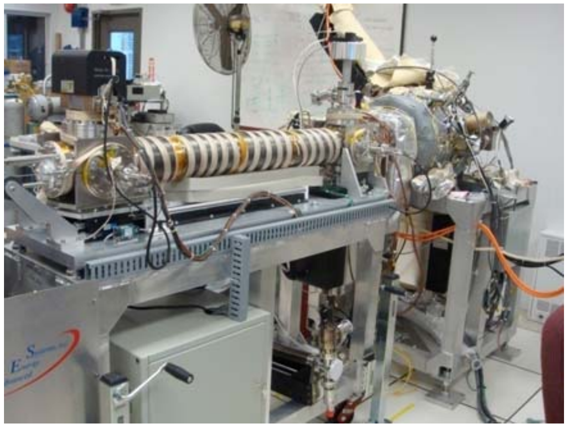

# High Quantum Efficiency Cathodes

Multi-alkaline Photocathode
Preparation chamber and load-lock

Diamond Amplified Photocathode

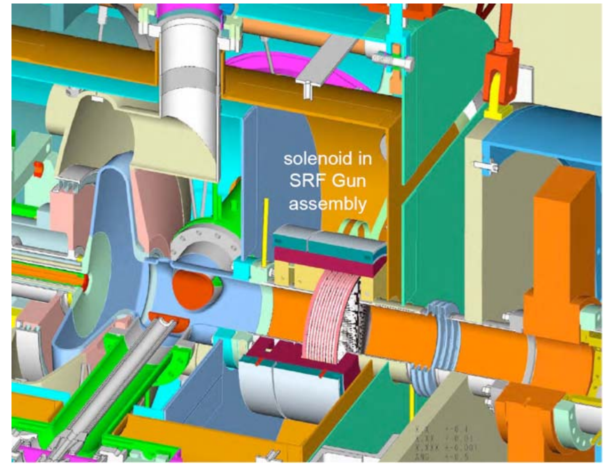


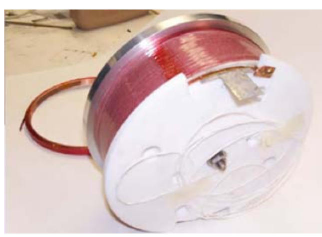



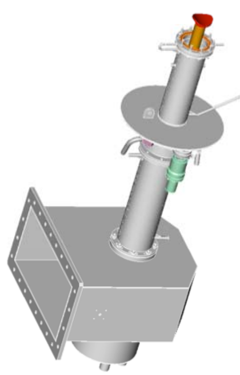
The Diamond Amplified Photocathode increases
the effective quantum efficiency by orders of magnitude.
Extremely robust Negative Electron Affinity cathode.

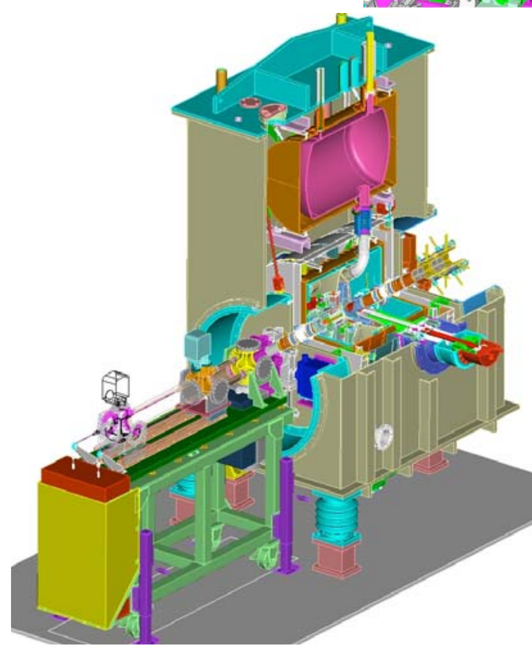
# High-current SRF electron-gun




- ½ Cell SRF injector
  - Demountable cathode stalk
  - HTS Solenoid
- UHV load-lock cathode
- MW twin couplers



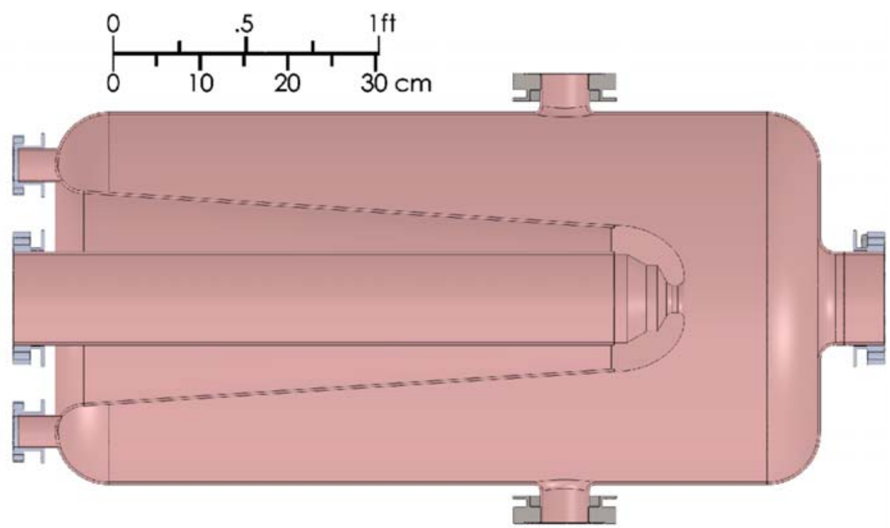




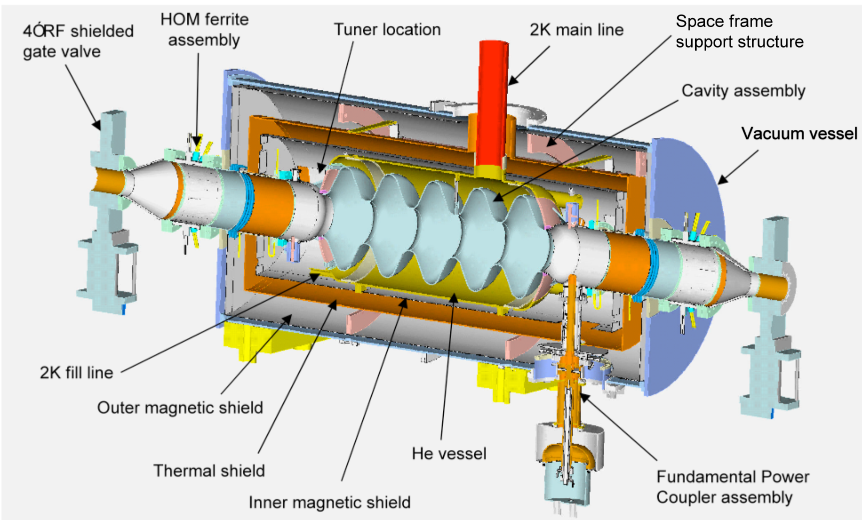
# 112 MHz SRF gun

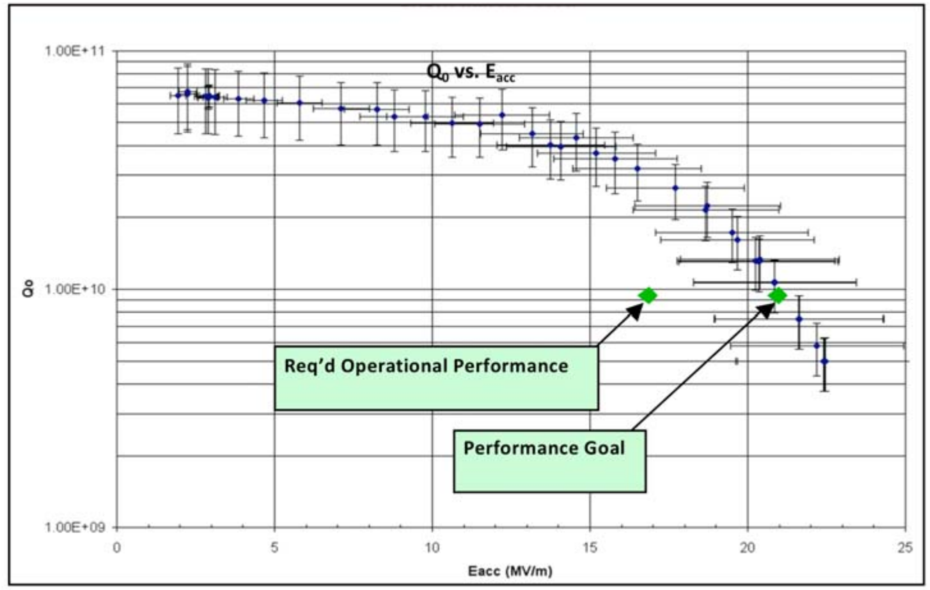
- 112 MHz gun, motivated by a low-energy electron cooling option
- Funded by Phase II SBIR to Niowave, Inc.
- Approaching completion

| | |
|---|---|
| Frequency (MHz) | 112.5978 |
| Vo (MeV, $\beta$=<0.98>) | 2.7 |
| Ecathode (MV/m) | 19.67 |
| Eo (MV/m) | 28.28 |
| Epeak (MV/m) | 51.29 |
| Bpeak (mT) | 97.83 |
| Bp/Ep (mT/(MV/m)) | 1.91 |
| Pd (W) | 16.55 |
| Q | 3.48E+09 |
| G (Ohm) | 38.25 |
| R/Q (Ohm) | 126.77 |
| TTF | 0.99 |



# A Prototype eRHIC Cavity

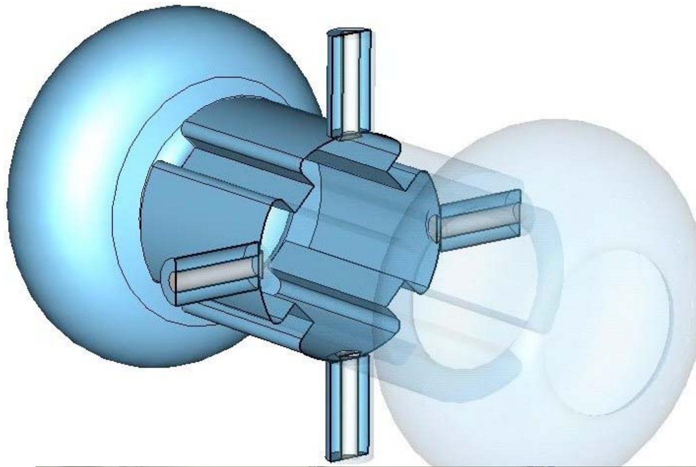


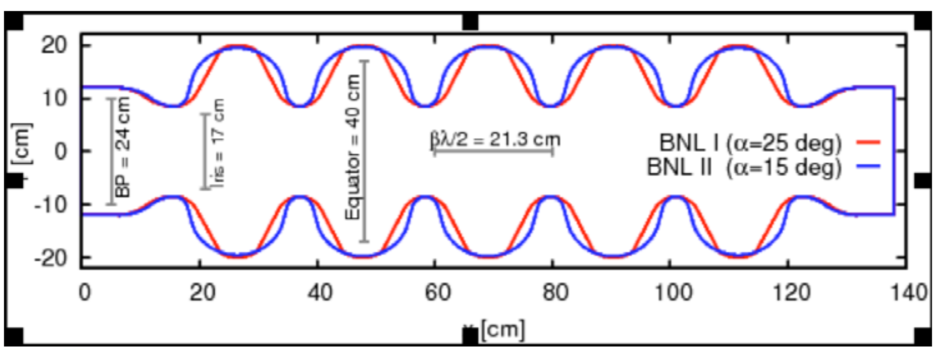



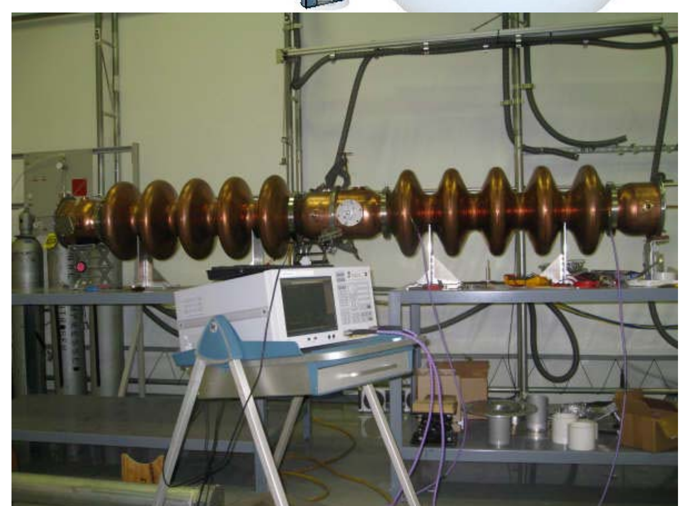

# eRHIC New Cavity Design

- Reduce peak magnetic field.
- Reduce stiffness.
- Apply new ideas in HOM damping.
- Reduce fundamental at HOM couplers
- Increase real-estate gradient
- Development / measurement program

New cavity design for eRHIC

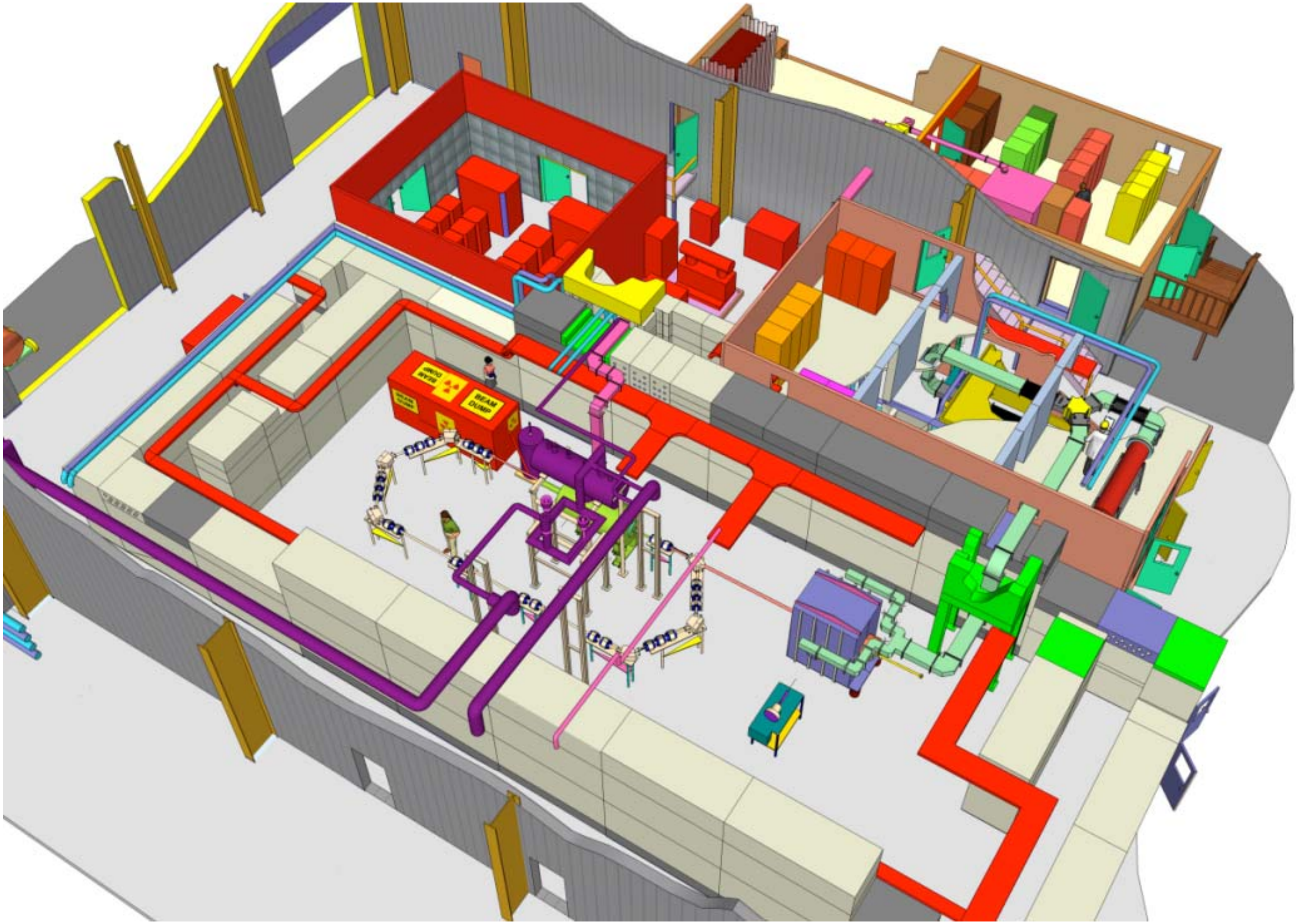




# R&D ERL

- eRHIC / MeRHIC have high current (multiple passes)
- Accelerator physics issues in a high-current ERL:
  - Bean breakup
  - Generation and removal of HOM power
  - Coherent radiation effects
  - Non-intercepting diagnostics
- For these reasons, and others, we are constructing the R&D ERL.
- The R&D ERL will be used for a Coherent Electron Cooling POP experiment




ERL layout

# ERL Beam Parameters

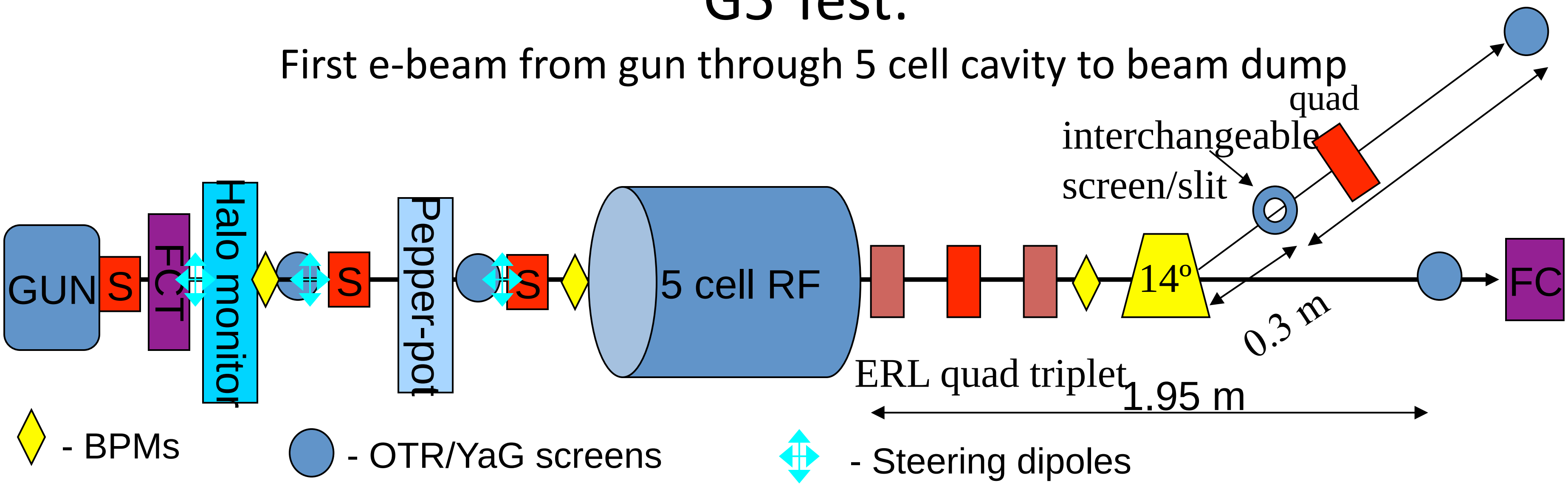
| | High Current-A | High Current- B | High charge |
|---|---|---|---|
| Charge per bunch, nC | 0.7 | 1.4 | 5 |
| Numbers of passes | 1 | 1 | 1 |
| Energy maximum/injection, MeV | 20/2.5 | 20/2.5 | 20/3.0 |
| Bunch rep-rate, MHz | 704 | 352 | 9.383 |
| Average current, mA | 500 | 500 | 50 |
| Injected/ejected beam power, MW | 1.0 | 1.0 | 0.15 |
| R.m.s. Normalized emittances ex/ey, mm*mrad | 1.4/1.4 | 2.2/2.3 | 4.8/5.3 |
| R.m.s. Energy spread, dE/E | $3.5 \times 10^{-3}$ | $5 \times 10^{-3}$ | $1 \times 10^{-2}$ |
| R.m.s. Bunch length, ps | 18 | 21 | 31 |

# Status of the R&D ERL

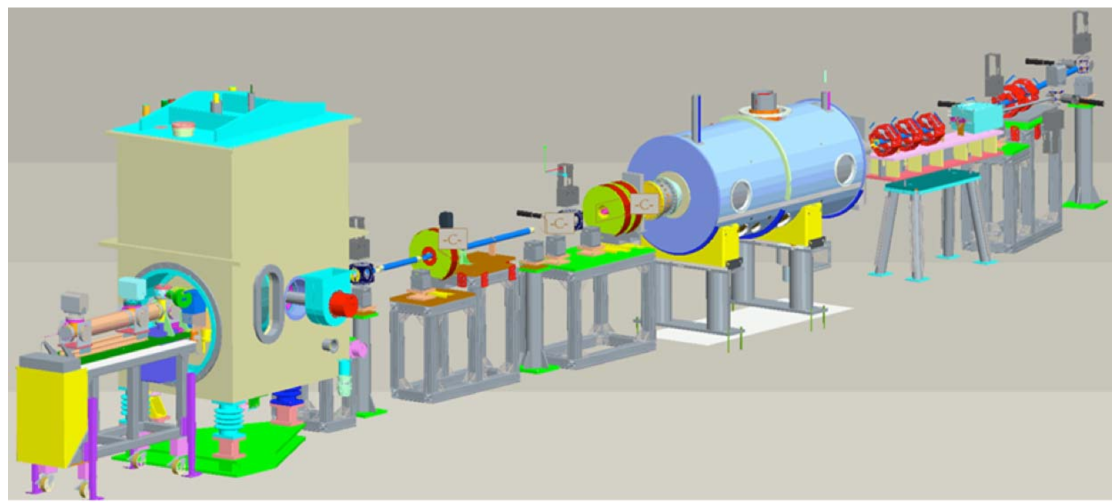
- The ERL is in an advanced stage of construction
- Beam will be generated next year
- Major systems are coming on


# G5 Test:

First e-beam from gun through 5 cell cavity to beam dump




Rich program of tests:
Gun, photocathode,
emittance, halo, more…
To be followed up by full ERL



# BNL R&D ERL Status: Completed items

- ERL Enclosure (Vault) was constructed (2005)
- 50 kW (for 5 cell 20 MeV SRF linac) installed, tested
- Recirculation loop magnets and injection line magnets have arrived  and measured.
- Dipole and quadrupole magnets power supplies were delivered, installation has been started.
- 1 MW Gun klystron (for SRF gun) including circulators and dummy loads installed, tested for full power 1MW (Summer 2008)
- ERL control room is finished (August 2008)
- PASS and Machine protection system is installed, tested well perform during the CET.
- 5cell cavity cryogenic system installed and fully functional (First cool-down T=2K, March 2009).
- The preparation chamber and the cathode transport car built, under commissioning. (AES designed, built, BNL improved, March 2009)
- 5-cell Cavity was processed and tested at JLAB, installed at 912. Cold Emission Test April 2009 22MV/m demonstrated.
- Radiation diagnostic tested during the CET (chipmunks, ionization chambers, Pin diodes, PMTs)
- Gun drive laser installed and tested (May, 2009)
- Loop vacuum system components are on hand
- RF control will be based on the new digital RHIC LLRF. The LLRF system is currently under development. 5cell cavity  CET  and FPC conditioning were done using  PLL based LLRF.

# Commisionnig plan:  in progress

✓We start commissioning of the R&D ERL components

✓5cell SRF cavity cold emission test

- first cool-down March, 14, 2009
- 20 MV/m in CET April, 23 2009

- Next CET scheduled for August 2009,
  - Will apply helium conditioning
  - Up-grated LLRF will be used, will try to tune the cavity during the test

- Refrigeration system will be installed March 2010, will be shared by ERL and VTF
- All magnets and vacuum components for G5 test will be installed
- Half cell SRF gun will arrive in mid 2010.
- LLRF based on new digital RHIC LLRF will be available for G5 test
- Control system for ERL needs to be completed

# Commisionnig plan: ERL fully operational in 2011

✓**G5 test (low average current) work in progress**

•First, the straight pass (gun - 5 cell cavity - beam stop) test for the SRF Gun performance studies. (October 2010)

#Metal cathode (low charge per bunch)

#Multi-Alkaline Cathode (up to 5nC per bunch)

•Next, a novel concept of emittance preservation in a beam merger at the lower energy will be tested (end of 2010)

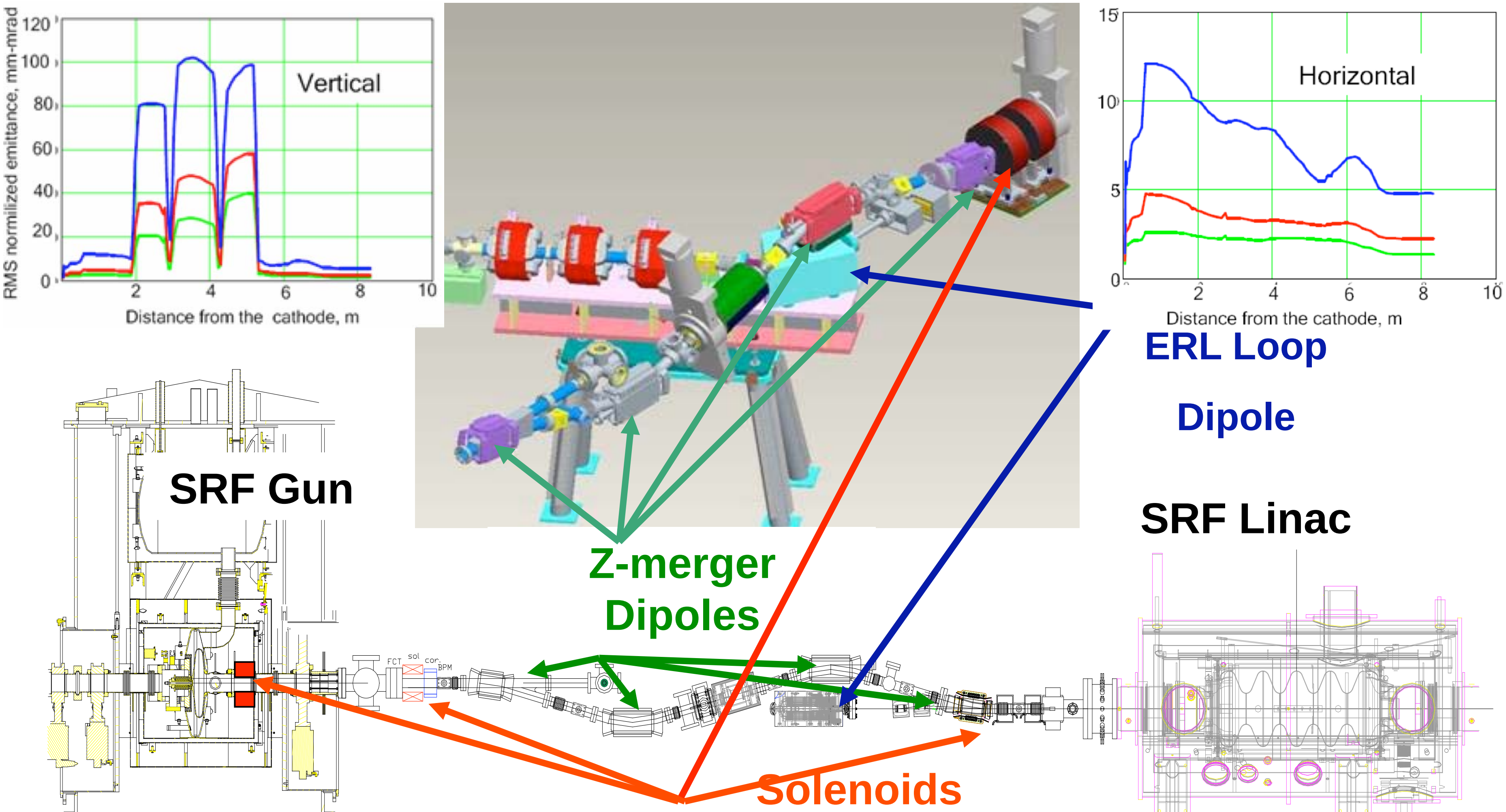
•After recirculation loop and extraction line completed, demonstrate energy recovery of high charge and high current beam. The prototype will serve as a test bed for studying issues relevant for very high current ERLs (2011)

•**Proof of principle coherent electron cooling ions in RHIC at ~ 40 GeV/n is feasible with existing R&D ERL parameters (ERL available around 2012)**

Thank you for your attention

Backup Slides follow

# BNL R&D ERL SRF Injector layout




PARMELA simulations shown: the small emittances can be achieved using bear-can initial distribution

| | | |
|---|---|---|
| Blue 5 nC | Red 1.4 nC | Green 0.7 nC |
| 4.8/5.3 um | 2.2/2.3 um | 1.4/1.4um |

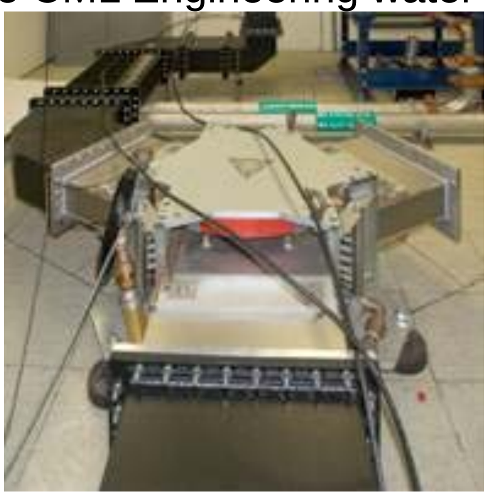
# RF power supplies

1 MW Klystron tested at its full output power of 1MW CW at 703.75 MHz. With the dummy load


50 kW Transmitter tested operational

Drive 5cell SRFcavity

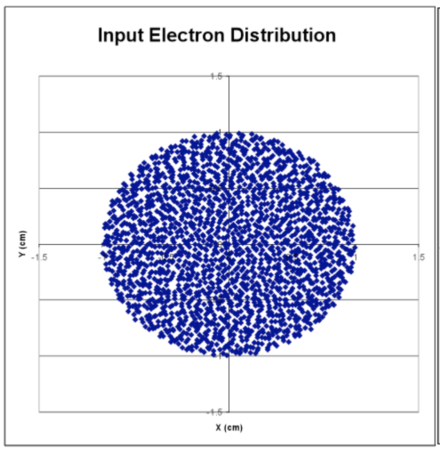
As part of system testing, one port of the AFT circulator was shorted, which directed all the power into the CML Engineering water cooled load. Both of these components performed as specified.

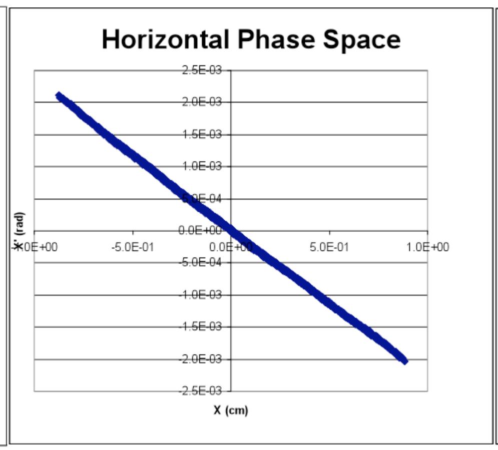


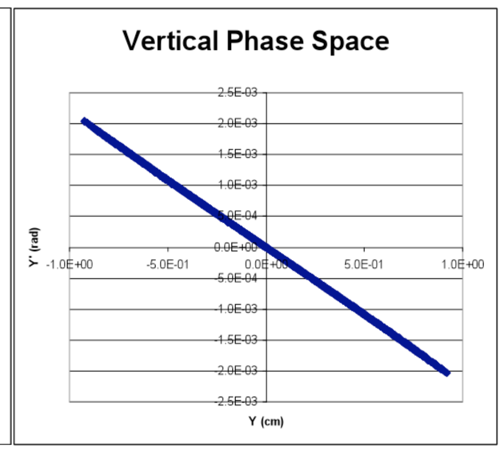
# Injection combined function magnets

Due to very small real estate and large beam size: each magnet includes 4 sets of coils: 1) vertical bend, 2) quadrupole focusing, 3) sextupole correction and 4) horizontal steering. The quadrupole coil is used to split focusing equally between the planes

Window-frame dipole for Z-bend




initial emittance 0

After tracking:

0.6 mm-mrad

(horizontal and

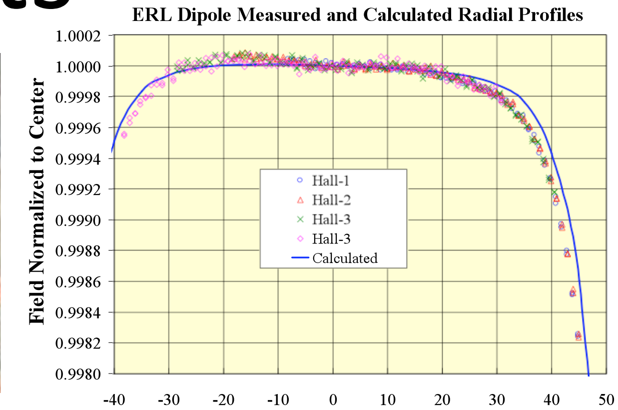
vertical).

Direct tracking in the calculated fields extracted from Opera3d was used of test beam to evaluate and to minimize influence of magnetic field on the beam emittance

# Loop Magnets

ERL 60 dipoles with vacuum chamber assembly


Measurement setup




Agreement between the measurements and simulations

Magnetic measurements of the ERL magnets employs both rotating coil and Hall probe array mapping, all completed.

Dipoles: the 60° dipole magnets have a small bending radius of 20 cm.
15° chevron edges are used to split focusing strength.

Quadrupoles: Strict requirements on field to preserve a very low normalized transverse slice emittance (εn~ 1mm-mrad). Verified by tracking in 3-D simulated field.

# Laser System

Lumera 5 W, 355 nm, 10 ps, 9.38 MHz laser system

- Installed. Tested already:
  - Power: 1064 nm- 20 W, 532 nm-10 W, 355 nm- 5 W
  - Pulse duration: ~ 10 ps
  - Pulse selection: single pulse to 100 kHz w/ variable pulse structure
  - TBD: Synchronization to <1ps
- Active program for generation of spatial and temporal flat top beam.